SUSTAINED PEAK LOW-CYCLE FATIGUE: THE ROLE OF OXIDATION RESISTANT BOND COATINGS

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Important developments in turbine blade technology, including cast thin-walled airfoils with complex internal cooling passes, place significant thermal gradients and stresses on the multilayered coating systems used to thermally insulate the blade from the hot combustion gases. As gas turbine engine operating temperatures increase, the intermetallic bond coatings traditionally used in thermal barrier coating systems undergo increased creep deformation. Bond coats for single crystal turbine blades have been designed primarily for oxidation protection with minimal consideration of mechanical and microstructural optimization. At higher temperatures, intrinsic failure mechanisms of coatings such as rumpling and cracking due to sustained peak low-cycle fatigue (SPLCF), limit the lifetimes of engine blades [1]. Bond coatings have been shown to extend or reduce the SPLCF lifetime of a specimen as compared to uncoated single crystals. The mechanical and microstructural properties bond coatings and their oxides that impact fatigue crack propagation rates have been investigated.

Figure 1 – Structure of a (Pt,Ni)Al coating after SPLCF cycling. Cracks are outlined in white.

Cylindrical fatigue bars of single-crystal René N5 were machined for loading along the nominal [001] direction. The gage length of the fatigue bars was coated with various bond coatings for investigation. Two traditional β-phase coatings were examined: a Pt-free vapor phase aluminide coating (VPA) and a (Pt,Ni)Al coating. Additionally, a γ' coating developed at UCSB and a γ-γ' coating developed at NIMS were considered [2,3]. Isothermal strain-controlled fatigue tests were completed at 982 °C and1093 °C with a strain ranges of 0.60% and 0.35%, respectively. Specimens were loaded compressively to the maximum strain, held for two minutes, then unloaded to zero strain.

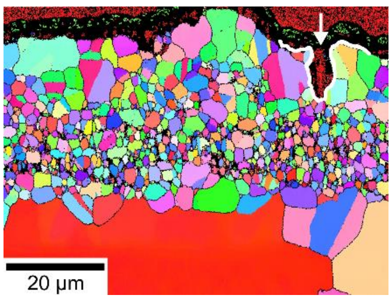

Figure 2 – Microstructure of a γ' bond coat produced via Ion Plasma Deposition (cathodic arc method)

During compressive dwell low-cycle fatigue, oxide filled cracks initiate at and subsequently propagate through the bond coating before entering the substrate. EBSD characterization shows cracks tend to propagate along grain boundaries in the bond coat, Figs 1 and 2. The microstructure of the bond coating depends heavily on the composition/phases present as well as the processing. Diffusion coatings produce large grains with a single grain frequently spanning the entire thickness of the coating, Fig 1. Overlay, or spray coatings, result in finer grain sizes and provide many boundaries for cracks to propagate along, Fig 2.

Finite element modeling suggests resistance to SPLCF cracking can be achieved via improvements in both the oxidation behavior and creep resistance. Changes to the oxidation behavior that either reduce the scale thickness or lower the oxide growth strains will decrease the TGO penetration rate in the bond coat. However, designing a bond coat with such properties remains a challenge. γ' coatings have the potential for higher strength, but with lower Al content, these coatings would require Pt-modification to prevent less desirable spinels and mixed oxides. β-NiAl coatings have excellent oxidation resistance but poor high-temperature strength. The influence of these competing bond coating properties on crack propagation will be discussed as well as important considerations for future coating design.

References

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